

Cuadernos de Investigación Geográfica <i>Geographical Research Letters</i>	2018	Nº 44 (1)	pp. 99-114	ISSN 0211-6820 eISSN 1697-9540
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DOI: <http://doi.org/10.18172/cig.3395>

WHEN THE WEATHER TURNED BAD. THE RESEARCH OF CLIMATE IMPACTS ON SOCIETY AND ECONOMY DURING THE LITTLE ICE AGE IN EUROPE. AN OVERVIEW

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ABSTRACT. *This paper focusses on historical climate impact research, one of the branches of historical climatology with an emphasis on the Little Ice Age. It provides examples of the theoretical concepts, models, and further structuring considerations that are used in historical climate impact research, which are especially fitting to the examined period. We distinguish between the impact of climate on society by time-scale in long-term, conjunctural or medium-term, and short-term impacts. Moreover, a simplified climate-society interaction model developed by Daniel Krämer is presented, as well as the concept of the Little Ice Age-type Impact (LIATIMP) by Christian Pfister and the vulnerability concept regarding climatic variability and extreme weather events. Furthermore, the paper includes a state-of-the-art application of the historical climate impact research and discussion of research gaps.*

Cuando el tiempo se volvió malo. La investigación de los impactos del clima en la sociedad y la economía durante la Pequeña Edad del Hielo en Europa

RESUMEN. *Este trabajo se centra en el estudio del impacto histórico del clima, una de las ramas de la climatología histórica, en este caso en relación con la Pequeña Edad del Hielo. Proporciona ejemplos de conceptos teóricos, modelos, y consideraciones estructurales que se emplean en la investigación histórica del impacto climático. Distinguimos el impacto del clima en la sociedad a distintas escalas, a largo plazo, coyuntural o a medio plazo, y a corto plazo. Por otro lado, se presenta un modelo simplificado de interacción clima-sociedad desarrollado por Daniel Krämer, así como el concepto de impacto del tipo de la Pequeña Edad del Hielo de Christian Pfister y el concepto de vulnerabilidad en relación con la variabilidad climática y el impacto histórico del clima y de los eventos extremos. Finalmente, el trabajo incluye una actualización de la investigación sobre el impacto histórico del clima y una discusión acerca de las lagunas de investigación existentes.*

Key words: historical climatology, social history, economic history, Middle Ages, early Modern period, Little Ice Age.

Palabras clave: climatología histórica, historia de la sociedad, historia económica, Edad Media, Edad Moderna, Pequeña Edad del Hielo.

Received: 2 August 2017

Accepted: 1 October 2017

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1. Introduction

The “Little Ice Age” is a term introduced by geographer François Émile Matthes in the 1930s to depict a period of cooling temperatures on a global scale during the second millennium CE (Behringer, 2010). The beginning and the end of the Little Ice Age (LIA) is still part of a debate. Depending on the region and a focus on summer temperatures or on glacier movements, the beginning of the LIA is set either at the beginning of the 14th or during the second half of the 16th century (Lamb, 1982; Grove, 1988; Pfister, 1999; Fagan, 2000; Le Roy Ladurie, 2004; Miller *et al.*, 2012; Matthews and Briffa, 2005; Brázdil *et al.*, 2013; Glaser, 2013; Hoffmann, 2014). In this paper, the period between 1300 and 1850 is considered the LIA. It does not mean, however, that the climate was continuously cooler during that period; the temperature variability was extraordinary and LIA also contains periods of remarkable heat (Landsberg, 1985; Pfister, 1999). An example is the year 1540 with an unusual heat wave and drought in Europe (e.g. Wetter and Pfister, 2013; Wetter *et al.*, 2014).

Historical climatology is a research field, which is situated between climatology and environmental history. In it, researchers examine the climate of the past based on documentary data from man-made archives (in a broad sense and including archaeological finds). Historical climatology comprises three branches of which the first concerns the reconstruction of climate, the second examines the societal impact of climate, and the third deals with the perception of climate and the history of knowledge of climate (Pfister, 1999; Brázdil *et al.*, 2005; Mauelshagen, 2010; Mauelshagen and Pfister, 2010).

This paper focusses on the second branch, or the societal climate impacts during the LIA in Europe. The paper aims to present concepts and models used in that field and a state of the art application of it. There are several existing state-of-the art papers, one of which gives an excellent overview on the three fields of historical climatology (Brázdil *et al.*, 2005). Because the field of historical climate impact research is very productive, it is worthwhile to reassess the state of the art from time to time – especially for research in appreciated epochs like the LIA. In addition, the paper will show research gaps and desiderata in the mentioned topic.

2. State of the Art

2.1. Concepts and models

Societal climate impacts can be structured not only in time but also in different levels of direct and indirect interaction between climate and society. Jan de Vries (1980) proposed a distinction between long-term, conjunctural, and short-term climate impacts on society, which also was discussed in the edited volume by Wigley *et al.* (1981). Such a distinction in the time-scale of the climate impacts on society is useful because it gathers similar events and invites a comparison of them over time and space; moreover, it shows how broad the range of climate impact types can be.

More recently, Krämer (2015) proposed a simplified climate-society interaction model, which has reached a broad impact (Luterbacher and Pfister, 2015). It was originally developed and enhanced from former attempts to explain the link between climate and society (e.g. Ingram *et al.*, 1981; Pfister, 1984, 2005). In this model, Krämer (2015) and Luterbacher and Pfister (2015) assume that climate variability and natural disasters—especially temperature and precipitation anomalies and further extreme events such as floods, droughts, storms, hail, and (forest) fires—cause first-order impacts on a bio-physical level. These first-order impacts include the primary production of biomass (food, feed, and fuelwood), water availability and the development of microorganisms. On the second level, prices of biomass and energy as well as transportation are affected. On the same level, the spread of epidemic and epizootic diseases is influenced by weather conditions (cf. Newfield, 2009; Slavin, 2012; Hoffmann, 2014; Campbell, 2016). Depending on the disease, e.g. humid and cool weather can favour or hamper the spread. As result, malnutrition, the decline of demographic growth and social conflicts are settled on the third level. On the fourth level, cultural responses such as crisis interpretation, cultural memory and learning processes are affected.

The influences of climate variability decrease on every ascending level because more and more other factors become important as well. As the model shows, there is a second branch of impact cascading from the fourth level to the first level. In this second cascade, religious rituals, amendments and various further adaptation strategies on the fourth level influence the third level, especially on grain supply, migration and public and private welfare. This can lead to market interventions, an expansion of the networks of terrestrial and waterway transport, and the linked infrastructure on the second level as well as a diversification of planted crops and the use of parcels in different altitudes and exposures on the first level. Finally, this first level can have an impact on climate variations, the appearance of extreme weather events, and so on. In this second cascade, the influence declines with every descending level.

Pfister (2005, 2007a) introduced the term “Little Ice Age-type Impact” (LIATIMP) to explain a specific type of climate impact on society which, in Central Europe, mainly caused by chilly springs and rainy mid-summers. This LIATIMP could concern the grain production through an elevated amount of precipitation. In autumn and winter, this would reduce the calcium, phosphates and nitrogen content of the soil. Extended rain in autumn furthermore would hamper the sowing of winter grain. Rain periods prior and

during the harvest would reduce the flour content of the grain corn and therefore the amount of food. It also would lead to the stored grain being more vulnerable to the spread of the grain weevil, other insects, infections and fungi (Pfister, 2005; Camenisch, 2015). A long-lasting snow cover until April could promote the spread of snow-mold and low temperatures in April would lower the yield of grain (Pfister, 2005). Low temperatures in winter, which lasted until late spring, could furthermore delay the growing of the plants and therefore lead to a late harvest, when the weather conditions already were more variable and less secure. Frost periods in April and May would cause great losses in the grain production as well (Camenisch *et al.*, 2016).

Regarding dairy production, the milk yield of the cattle such as cows and goats were dependent on the amount of daily available food (e.g. grass, hay) for the animal. This feed amount, however, was influenced by the duration of the snow cover and the temperatures in autumn and spring (Bracher, 2016). A poor hay harvest had an impact on the amount of milk in the subsequent winter. In this context, it is important to remember that the purpose of cattle breeding was not limited to milk production but also to obtain animal protein for human nutrition, the gain of muscle power by using draft animals for ploughing, manure production, leather production, and so on (Pfister, 2005). Wine production also depended on favourable weather conditions. Like grain, vine plants are sensitive to frosts in April and May. Wet spells from late June to early August would greatly reduce the size of the grape harvest. In contrast, the sugar content of the grapes is dependent on a warm and sunny period immediately before harvest, in September and early October. The LIATIMP comprises crop failures like those described not as single events but as widespread crop failure of several crops (Pfister, 2005).

The concept of vulnerability is often used to assess societal impacts of climate and natural disasters (e.g. Adger, 2006; Pfister and Brázdil, 2006; Füssel and Klein, 2006; Voss, 2008; Pfister, 2010; Collet, 2012; Collet *et al.*, 2012; Engler, 2012; Krämer, 2012, 2015; Curtis, 2014). In this concept, a system is vulnerable to certain hazards (e.g. extreme weather conditions). The type and number of the stressors, their root causes, the effects on the systems as well the time horizon of the analysis are decisive (Füssel, 2007). To assess the vulnerability of a certain part of a system such as an individual, household, society, state, animal plan or ecological system, it is necessary to know more about the exposure of the object and how often it is affected by a hazard. Furthermore, it is important to know the sensitivity of a system or to what extent it will be changed by bio-physical, socioeconomic and political processes caused by the hazard. Finally, the resilience of the object and its adaptation strategies must be considered (Krämer, 2015).

Vulnerability factors can be classified into the dimensions of sphere and knowledge domain. Within this frame, there are internal and external factors on the one hand and socioeconomic and biophysical factors on the other hand. As Füssel (2007) described, "Taken together, these four categories constitute the vulnerability profile of a particular system or community to a specific hazard at a given point in time". As Füssel (2007) and later Krämer (2012, 2015) demonstrated, the vulnerability factors of the biophysical domain's internal sphere include topography, environmental conditions, land cover and soil conditions. The factors of the external sphere comprise non-weather-related natural hazards (e.g. earthquakes),

weather anomalies, and extreme weather events (e.g. severe storms, or sea-level changes) as well as epidemic and epizootic diseases. In the socioeconomic domain, the internal sphere includes household income, social networks and access to information whereas the external sphere is composed of national policies, international aid, economic globalization, wars, taxes and fees, grain export bans and embargoes.

2.2. State of the art

2.2.1. Climate impacts by time-scale

The origin of the modern climate impact research goes back to a conference organised by Hubert Horace Lamb in Norwich in 1979. The resulting edited volume with the main findings not only represents the state of the art at that moment, it also shows the enthusiasm of the mostly young researchers then. Many of the results still are topical and of great value (Wigley *et al.*, 1981; therein e.g. Anderson, 1981; Flohn, 1981; Lamb, 1981; Mackay, 1981; Parry, 1981). In the same year, an edited volume by Rotberg and Rabb (1981) appeared with a focus on climate impacts on society, which also contributed with useful methodological thoughts (e.g. Appleby, 1981; de Vries, 1981; Post, 1981). A further early milestone are the papers edited by Kates, Ausubel, and Berberian in 1985 (therein e.g. de Vries, 1985; Kates, 1985; Wigley *et al.*, 1985). As already mentioned, de Vries (1980) proposed a distinction between long-term, conjunctural, and short-term climate impacts on society. In the following sub-chapters, publications focussing on the societal impact of climate during the LIA will be presented.

2.2.1.1 Long-term impacts

Amongst the long-term impacts are the collapse of empires, migration of nations or similar epochal events. In this time-scale especially, the studies of Braudel (1949) and Lopez (1962) need to be mentioned. More recent are the findings of White (2011) who sets the change of political structure in the Ottoman Empire during the 16th and 17th century in the context of the climate of the LIA. Furthermore, Parker (2013) showed the link between climate change and severe political and demographic crises in mighty empires across the world in the mid-17th century. McNeill (2010), however, did not only look on the climatic impact on the rise and fall of empires in Central America, but also on the influence of the whole eco-system. Moreover, Wanner (2016) published an overview on climate and human beings during the last 12,000 years. As a matter of course, all these authors clearly show that climate is one factor of several and there is no mono-causal explanation for complex societal change.

2.2.1.2 Conjunctural or medium-term impacts

Medium-term or conjunctural impacts are understood as climate impacts on society that have a repetitive inter-annual influence. Regarding these impacts, de Vries (1980) focussed on the influence of weather conditions on harvest size and the prices of bread grain. The analysis of grain prices has a long tradition and most of the researchers operating in this field acknowledge an influence of weather conditions on prices (e.g. Beveridge, 1921, 1922; van der Wee, 1963; Brandon, 1971; Neveux, 1974; Braudel,

1979; Bauernfeind, 1993; Bauernfeind and Woitek, 1996; Bauernfeind *et al.*, 2001). Nonetheless, except for Pfister (1975, 1984, 1988, 2004), these authors could not examine the relation between weather conditions and prices in detail due to the lack of reliable climate data for the LIA in those years.

In 1981, de Vries assumed that the link between weather and prices was not as close as one could expect. The statistical correlations between weather conditions and tithe data, for instance, are rather weak as demonstrated by Bowden (1967) and Pfister (1975). Later, Pfister (1984, 1988) used more elaborated methods and better data on the reconstructed climate and consequently proved a closer link between climate and grain prices. Also for the Burgundian Low Countries in the late Middle Ages, it was possible to give evidence for a close relation between seasonal climate indices and grain prices (Camenisch, 2015). Decisive in that matter was the availability of high-resolution climate data. In epochs before instrumental measurement, this is only possible when enough sources of essential quality exist for the examined region and period. Moreover, in sources of the late Middle Ages and early modern period, the link between weather conditions and prices seems to be closer than between weather conditions and crop yields. The reason for this is most likely the fact that prices usually represent an extended geographical area whereas data on crop yields derive from a much smaller area – a couple of fields, for instance. Both prices and tithes or other yield data are influenced by many other factors beyond weather conditions anyway (Camenisch, 2015).

Ingram *et al.* (1981) proposed to add the impact of medium-term, interannual climatic fluctuations to this category. This encloses clusters of extreme seasons and individual weather events. For this paper, we decided that at least three consecutive years of impacts were necessary for a classification as a medium-term impact. The societal impact of such clusters regarded as medium-term also has been examined for the LIA. Examples of this include the 1430s – a cluster of extremely cold winter seasons (Camenisch *et al.*, 2016) – and the 1680s and 1690s, which was the coldest phase of the Late Maunder Minimum (1675–1715 CE) with a very specific climate pattern (Lamb, 1982; Lachiver, 1991; Barriendos, 1997; Luterbacher *et al.*, 2001; Zwitter, 2015).

2.2.1.3 Short-term impacts

The impact of short-term weather extremes and variability as well as weather-induced natural disasters is the object of many analyses. Amongst these short-term impacts, the research on subsistence crises plays a major role. Because subsistence crises also take a very prominent place within the model presented by Krämer (2015), they are discussed in section 2.2.2 in more detail.

Regarding short-term impacts, natural disasters induced by extreme weather must be mentioned. A couple of rather recent publications include the societal impact of this type of natural disasters (Kempe and Rohr, 2003; Rohr, 2007, 2008; Schenk and Engels, 2007). Amongst those disasters are storm surges (Jakubowski-Tiessen, 1992; de Kraker, 2000, 2002, 2005; Soens, 2013), avalanches (e.g. Rohr, 2009a), floods (Brázdil *et al.*, 2010; Rohr, 2005, 2006, 2012a, 2012b, 2013; Kiss, 2018), and locust invasions (Rohr, 2009b, 2014).

It is necessary, however, to be conscious of the limits of such a distinction between the possible different time scales: series of short-term impacts may form a conjunctural or medium-term impact. Also long-term impacts contain short-term impacts and conjunctural or medium-term impacts. Therefore, one should be aware that this time-related distinction is a structure that shall lead to a better understanding of the societal climate impacts and not be an axiomatic certainty.

2.2.2 Climate impacts by impact-level

Climate impacts on society also may be structured by following the simplified climate-society interaction model presented above. This structure presents the results of analyses including societal impacts (e.g. Camenisch *et al.*, 2016).

Amongst the first-order impacts, the production of biomass is very important. Hence, there are few studies analysing the relation between weather conditions and grain crop yields (e.g. Pfister, 1981a; Bourke, 1984; Stern, 2000; Franzén and Söderberg, 2006; Litzenger, 2015). More data exist on wine production where often the harvest date plays an important role for climate reconstructions. Some of these analyses also included the quantity of wine harvest into their considerations (e.g. Pfister, 1981b, 1984; Kiss *et al.*, 2011; Litzenger, 2015).

Rising food prices and consequently subsistence crises as an extreme case of high food prices occurred repeatedly during the LIA (Collet and Schuh, 2018). A subsistence crisis always is caused by many different factors, but not only by adverse weather conditions and rising food prices (Camenisch, 2015; Krämer, 2015). Many famines already have been examined for certain regions. The Great Famine from 1315 to 1320 is one of two harsh demographic crises that hit European society during the 14th century (Jordan, 1998; Campbell, 2009, 2016; Huhtamaa, 2015; Slavin, 2017). The famines of the 1430s, 1480s, and 1490s also must be mentioned (Jörg, 2008; Camenisch, 2015; Camenisch *et al.*, 2016). A couple of the great subsistence crises of the 16th, 17th, and 18th centuries have also been examined for certain regions in Europe (and the world) (Lachiver, 1991; Le Roy Ladurie, 2004, 2006; Parker, 2013).

Due to the bicentenary of the Tambora eruption in 1815 and the following famine in 1816 and 1817, a couple of publications dealt with the extreme weather events and seasonal anomalies caused by the volcanic eruption in Indonesia and its impact on society (D'Arcy Wood, 2014; Krämer, 2015; Luterbacher and Pfister, 2015; Behringer, 2015; Brönnimann and Krämer, 2016; Flückiger *et al.*, 2017).

Regarding human and animal epidemic diseases linked to climate, Campbell's (2016) pathbreaking work must be mentioned as well as recent findings focussing on cattle (Newfield, 2009; Slavin, 2012).

Amongst the fourth-order impacts are a variety of phenomena and processes. Many of them are described in a volume edited by Behringer *et al.* (2005). It would go too far at this place to discuss each of them. Instead, a few examples shall be presented. The perception and interpretation of natural hazards and extreme weather events are crucial for the understanding of the interaction between climate and society. There is already

in-depth research done in this field, especially for the Eastern Alpine area (Rohr, 2003, 2007, 2008). Examinations of the religious rituals used as a coping strategy are found in works by Barriendos (1997, 2005), Bauch (2016) and Jakubowski-Tiessen and Lehmann (2003). The phenomenon of scapegoat hunting, which includes pogroms against Jewish individuals and societies, witch hunting, and the hunt for religious and social minorities, has also been examined in recent years (Behringer, 1995, 1999, 2004; Pfister, 2007b).

3. Desiderata

As we have shown above, a considerable number of studies published in the last years has focussed on the societal impact of climate during the LIA. Nonetheless, we need more research in this field, especially further in-depth studies of not-yet-explored source material across Europe. There is plenty of evidence in historical archives, which has never been examined under the question of climatic impact on society. It is necessary to bring results from a wider geographical area together to assess the magnitude of events and to compare the impacts and the coping and adaption strategies of societies from different places and in different environments.

Also, areas that are not in the very centre of Europe play a very important role. Although there are recent publications (e.g. Ogilvie and Jonsson, 2001; Huhtamaa, 2015, for the example of border regions in Scandinavia), there are still huge gaps. On the one hand, information from Scandinavia, Ireland, Bohemia, or South Italy helps to estimate the dimensions of drought impacts, famine, or the spread of an epidemic disease. On the other hand, they often show different coping strategies. For instance, the peasants in Finland applying slash-and-burn agriculture and having access to deer hunting and fishery that was not regulated by the government (Huhtamaa and Helama, 2017) had different coping strategies against extreme weather than the citizens of the prosperous metropolises of the Low Countries.

Moreover, further research on all levels of Krämer's model would be appreciated. More studies on crop yields, for instance, would help to close the gap between the weather and prices. It also would bring together two parts of the same society: the countryside where the crops were produced and the urban sphere where the prices were made on the markets.

As Campbell (2016) has shown with his recent masterpiece, there are stunning links between the epidemic disease of the Black Death (*Yersinia pestis*) and climatic variability. Later plague waves or the link between other epidemic diseases are investigated much less. The demographic impact of extreme weather and natural disasters needs to be investigated further as well as the fourth-order impacts of these phenomena. The crisis interpretation and learning processes are promising fields, which particularly need more research.

4. Conclusions

Within historical climatology, the research on climate impacts on society is of considerable importance. Although the reconstruction of climate based on historical sources is settled on the interface between natural sciences and environmental history,

historical climate impact research is linked more closely to economic and social sciences and history.

To understand the complex relationship between climate and society, historical climate impact research is dependent on classifications, models and theoretical concepts. Amongst them are those presented in this paper. The classification following a division of climate impacts on society by time scale, as well as the climate-society interaction model, the LIA-type impacts and the concept of vulnerability are useful in understanding and interpreting climate and society.

Historical climate impact research is a very productive research field, and recently many new results have been published. By far, not all recent and important publications could be listed in this paper, but this overview should give an impression of the most important papers, monographs and edited volumes. Nonetheless, there are many gaps in the research field including many (archival) sources which were never investigated in all areas of Europe but especially for Scandinavia, Ireland, Bohemia, South Italy, or the Balkans and desiderata at all different levels of climate impacts, notably on crop yields, the interaction between weather conditions and diseases, crisis interpretation, or learning processes.

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